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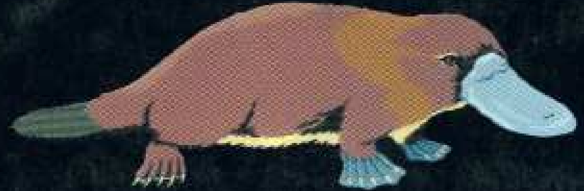

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EVOLUTION – RENEE BORGES

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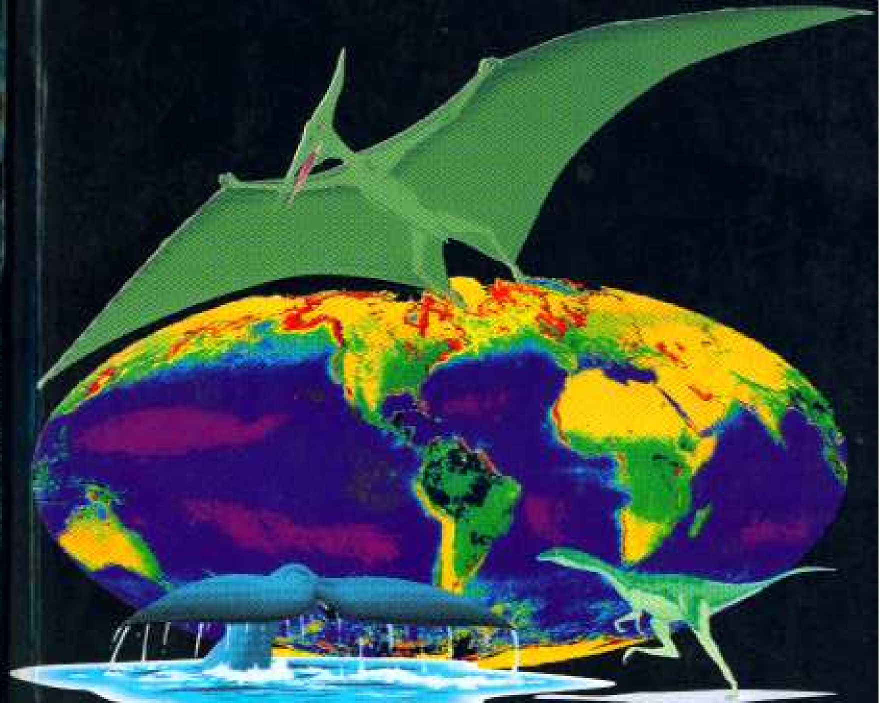
Evolution

– the story of life

Renee Borges



Edited by Bittu Sahgal

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Series Editor, Bittu Sahgal

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Evolution

– the story of life

This is a simply written account of some of the most complex and fascinating mysteries ever to have confronted mankind. How did life on earth originate? How did we come to inhabit the planet in the company of such a bewildering array of plants and animals? Why did the dinosaurs grow so large? How are new species formed?

The author, *Renee Borges,* specialised in ecology and evolutionary biology at Florida, USA. She is interested in plant-animal interactions and behavioural ecology. She studies giant squirrels as well as pollination and dispersal systems of plants in the Western Ghats. She also works with the Mahadeo Koli tribe of the Bhimashankar Wildlife Sanctuary in Maharashtra where she has spent time investigating their patterns of natural resource utilisation.

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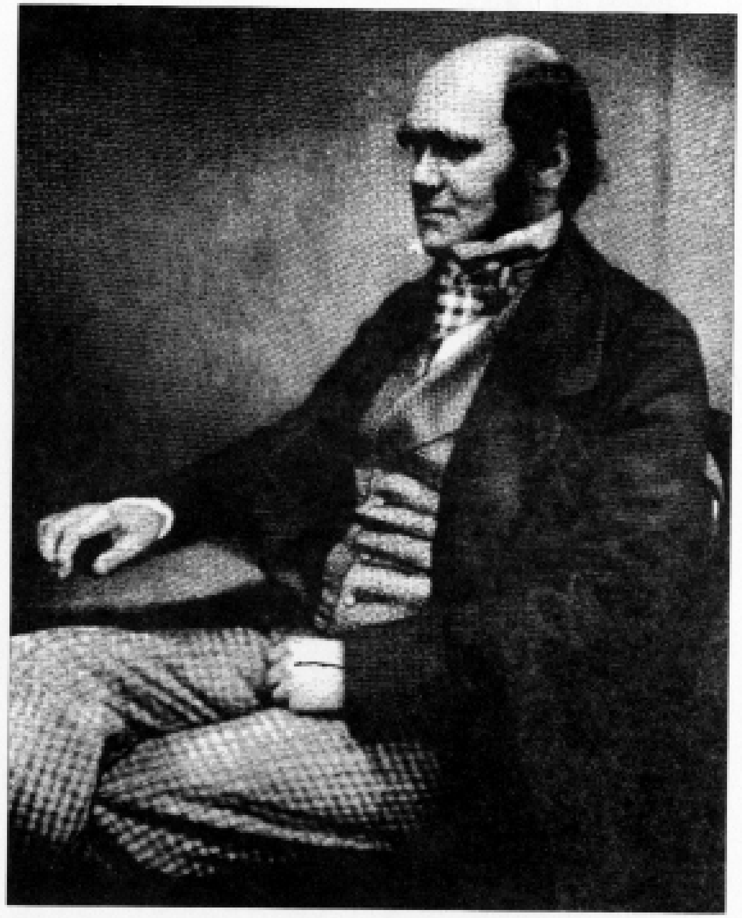
Charles Darwin

1809 - 1882



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Editor's Note

The Bombay Natural History Society (BNHS) has been a fount of knowledge for over a century. It has created and nurtured thousands of naturalists from all walks of life. Today the Society continues to add to the body of information gathered by all-time greats such as R.W. Burton, E.P. Gee, J.B. S. Haldane and, of course, Dr. Salim Ali, the 'Grand Old Man of Ornithology.' Long before the subject of environment had become fashionable; before the word biodiversity had even been coined, the study of nature was a mission for hundreds of BNHS members. In time this enduring institution gave birth to an amazing network of amateur naturalists. Their prime joy, apart from tramping India's wilds, has always been to share their experiences, knowledge and information about nature with others.

It is in this context that the production of the National Council for Science and Technology Communication, *NCSTC-HORNBILL Natural History Series* should be viewed. India is losing its natural wealth at a frightening pace and it is vital that decision-makers are exposed to the very real value of the ecological assets being lost to the nation. It is equally important that the rationale for wildlife conservation is understood. Humans, for instance, do not possess the technology to re-create the millions of hectares of natural forests, grasslands and wetlands we lose each year.

To maintain and to enhance the green mantle, which protects our soils and our water sources, we need the elephant to transport mango seeds. We also need chital to carry grasses from one part of the forest to the other as we do the tiny leaf warbler's non-toxic 'pest control' contribution. The cleaning service performed by turtles and crocodiles, frogs and the larvae of dragonflies helps make the water in our lakes and rivers drinkable. Every creature on Planet Earth performs a useful ecological role... save for *Homo sapiens.*

We probably started out right, but our capacity for abstract thought, our intellect and our relatively recent penchant for consumerism, have lulled us into the mistaken belief that we can escape the consequences of the grevious damage we inflict on ecosystems and species.

With each forest we lose, each river we degrade, each mangrove and coastline ecosystem we alter, the viability of the Indian subcontinent to sustain future Indians is diminished. Simultaneously the quality of life of perhaps over 100 million earth-people: among them, fisherfolk, forest dwellers, nomads and pastoralists... is lowered and their security compromised.

This latter aspect of the environmental and wildlife movements has only just begun to assert itself in our national psyche. Young people everywhere, social activists and human rights groups are fast recognising that protecting forests for the tiger, rhino and elephant automatically serves to protect both forest cultures and resources for communities which live outside the market system.

In the coming days this new partnership between naturalists and earth-people is destined to play a vital role in defending wild India. Towards this end the work of field biologists such as *Renee Borges* will go a long way in helping land managers make more rational decisions.

If the *NCSTC-Hornbill Natural History Series* manages to enhance the ecological information base of such initiatives and to replace pure sentimentalism with pragmatism in the battle to save nature... our purpose will have been admirably served.

Bittu Sahgal, Editor
NCSTC-Hornbill Natural History Series

Publisher's Preface

This is one of a series of booklets that have been in the making for years! The wait has been worth it... both in terms of the contents and the fact that we have been able to win the involvement of the most authoritative authors on the various subjects chosen for the titles in the National Council for Science and Technology Communication, *NCSTC-HORNBILL Natural History Series*. NCSTC and the Bombay Natural History Society (BNHS) joined hands to bring the science of natural history to young people though adults too are sure to relate to the style and straightforward presentation. We intend to produce more titles each year to cover as wide a spectrum of nature as possible. We expect the publications to serve the dual purpose of disseminating information and keeping an archival record on the eve of the next millenium.

We wish to demystify the subject of ecology... to make it both understandable and acceptable to India's future decision-makers. The inter-relationships, the complex webs of existence, the contentious and confusing environmental issues... all these will need to be understood and grappled with by tomorrow's citizens. To the extent possible we have stayed away from scientific jargon for obvious reasons. We did not wish this initiative to be reduced to an isolated 'lesson' of the kind one often sees being taught in our schools and colleges.

In this book you will be introduced to the subject of evolution. and how this earth came to be what it is... with all the wonder, beauty and interelationships we see around us. Dr. Renee Borges is a scientist with vision and we are sure that readers will benefit from her mind. We trust that this (and the other titles in the series) will encourage readers to search for the larger picture, the totality of inter-relationships... and thus better understand our own role on this planet.

Dr. Narender Sehgal, Series Publisher,
Director Vigyan Prasar, June 5, 1997

The battle between evolutionists and creationists has raged ever since Darwin put forth his now accepted theory of evolution. This panel is one among thousands of art works handed down through the generations. Published in a 16th century bible, it depicts the then accepted theory of the creation of the world in six days.

If you sit on a rock overlooking a valley in the hill station of Mahabaleshwar in the Western Ghats, you will see before you a mountain chain that is built of many horizontal layers of hard, black basalt. The rock on which you sit, forms part of the Ghats and of the Deccan plateau, and is 65 million years old, as old as the time when the dinosaurs vanished from the earth in a mysterious mass extinction. This basalt was spewed out from the earth in many volcanic episodes and spread in layers over the western portion of India as she drifted away from Africa en route to her collision with Asia. When you travel from Bombay to Bangalore and approach Dharwar, you leave the basalt behind, and you are now on a base of granite – the rock of the ancient continental shield. You can see fence-posts and roofs made from slabs of this ancient granite.

If you venture into a bamboo coracle in the waters of the Krishna near Srisailam, layered walls of sandstone will tower over you, each layer breathing history. This time, the layers are formed by sedimentation, the river carrying layers of silt, which slowly accrete to tell their story. In the sedimentary rock formations of the Godavari valley, concealed in the layers, are fossils including those of dinosaurs.

When you visit the holy shrines at Haridwar and Rishikesh in north India, you will be close to hills called the Siwaliks made of loose micaceous rock, fragile and crumbling. These are nothing but mounds of sea sediments that heaped together when the Indian continent collided with the Asian continental plate after breaking away from Gondwanaland. The Indian plate slid beneath the Asian plate, obliterating the intervening Tethys Sea, and uplifting the Himalaya. That momentous event formed the Siwaliks – fragile twin of the Himalaya. And so, amongst the blinding white snows of the great Himalaya may be found fossils of the ancient

creatures of the Tethys Sea. When you travel from Madras to Port Blair in the Andaman Islands, you will see beautiful forested islands emerging out of the water. These islands are merely the tops of a mountain range called the Arakan Yoma, which now lies mostly submerged by the sea. At one time in the past, the Arakan Yoma stretched above land all the way from Myanmaar. Today, the sea levels have risen, submerging the mountains, leaving only the tops exposed. Only a few of these islands, like Narcondam, are of volcanic origin.

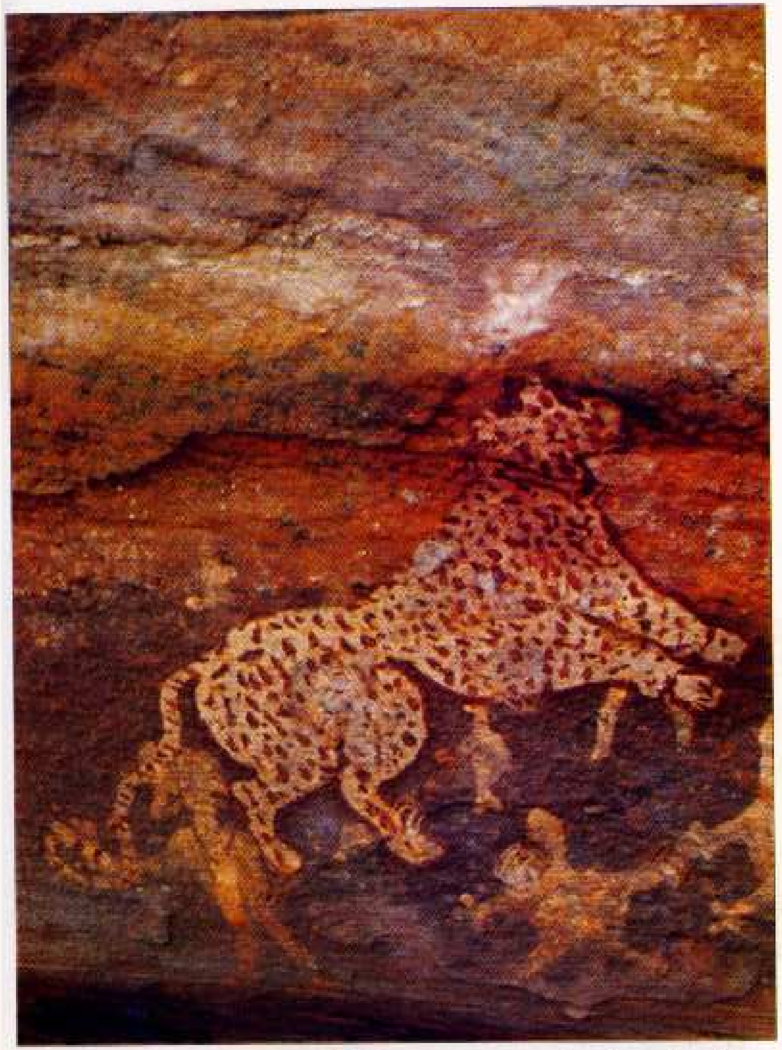
Land and sea and underground forces have met, merged and separated many times in the history of the earth. Some of this turbulent history is written in the rocks, and on the floors of the ancient seas, and has been read by man. But much of this history is still conjecture, still waiting to be unravelled.

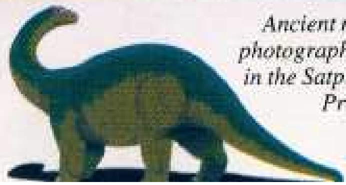
"In the rock formations of the Godavari valley, are the fossils of dinosaurs."

The origin of life

The earth is a special place. A photograph taken of "spaceship" earth from outer space by the lunar astronauts evocatively showed us how special, unique and fragile it is. The blue oceans, white clouds, polar ice caps and the dark continents that cover the earth have an ethereal beauty. The earth is the only member of our solar system (and perhaps even of other solar systems in our galaxy) that has blue swirling oceans in which life was born, the only known planet to possess life based on carbon chemistry in the way we understand it. How did this life begin and why?

About 4.5 billion years ago, a huge cloud of rotating gas started to contract under its own gravitational attraction. The largest body formed by this process was the sun at the centre of our solar system, while smaller masses of rotating gaseous material escaped





Ancient rock paintings photographed at Churna in the Satpuras, Madhya Pradesh, record the passage of time.

A fern fossil (above) recovered by the author from an open-pit coal mine in France is probably from the Carboniferous period. The ammonite (top), found in the Thar desert near Jaisalmer in Rajasthan, points to the fact that this vast desert was once submerged by ancient oceans.

the sun's gravity to orbit around the sun and began to condense by their own gravitational forces to form the planets. By simple centrifugal forces, the outermost planets such as Jupiter, Saturn, Uranus and Neptune were formed with lower density material while the inner planets like Mars, Earth, Venus and Mercury were made of denser matter.

The mass of the earth, the size of its orbit, and its distance from the sun are of utmost importance to the earth. This is because there is only one area called the "continuously habitable zone" (CHZ) around the sun in which a planet can retain water in liquid form on its surface. Mars, for example, is a small planet and is situated farther away from the sun than the earth. Therefore, it is an arid desert either because it has weaker gravitational forces, which have allowed all its water to escape from its atmosphere, or because its water has frozen owing to its distance from the sun. Venus, on the other hand, is very close to the sun and is consequently so hot that any liquid water it may have had could not condense.

"If the earth was one per cent farther from the sun, it would have had no liquid water."

It has been calculated that the CHZ extends from a radius equal to one per cent larger than the earth's orbit to a radius five per cent smaller than the earth's orbit around the sun. If the earth had randomly formed one per cent farther away or five per cent closer to the sun, there would have been no liquid water on the earth. Also if the sun had been less than 83 per cent of its present size, it would not have been able to radiate sufficient heat to keep the water on earth from being permanently frozen. And if the sun were 20 per cent larger than it is, the heat generated by its collapsing mass would have caused it to burn up all its nuclear fuel

within less than a billion years, resulting in its early death. Our sun has been with us for 4.5 billion years, and it took a billion years after this for life to first evolve in the oceans. The blue swirling oceans that the astronauts saw from outer space are symbols of the lucky randomness that brought us all into existence.

As the earth cooled and condensed, the heavier elements like iron and nickel were concentrated within the molten core while the lighter elements such as magnesium and silicon were distributed on the exterior. The early earth was restless due to the shifting and settling of matter and there were earthquakes and volcanic eruptions. These released hot gases from the interior of the earth and in about 100 million years, enough gases had been released to form an atmosphere of oxygen, hydrogen and nitrogen around the earth. This atmosphere was different, however, from our present atmosphere because there was little free oxygen. There was also no protective ozone layer around the earth. So, the ultraviolet rays from the sun could easily reach the earth's surface.

"Stanley Miller demonstrated the possible origin of life using early materials."

Under conditions of high temperature and in combination with electric sparks from the thunder and lightning storms, hydrogen may have combined with oxygen to form water (which condensed to form the oceans), with carbon to form methane and with nitrogen to form ammonia. Further action of heat and electric discharges on these molecules could have resulted in the first organic molecules within the newly formed oceans.

The possible origin of life using early available ingredients was demonstrated in a very famous experiment conducted by Stanley

Miller at the University of Chicago in 1953. Miller introduced ammonia, methane and hydrogen (representing the early earth's atmosphere) into water boiling in a flask (equivalent to the early hot oceans), and passed an electric current through the system to simulate an early electric storm. He analysed the mixture after a week and found that several organic molecules such as amino acids (the elementary building blocks of proteins) and carbohydrates had been spontaneously formed. Further experiments conducted by Sidney Fox at the University of Miami showed that by heating amino acids for long periods of time, they could join together to form chains of molecules called peptides which are larger building blocks of proteins. Cyril Ponnamperuma also showed that sound energy (from volcanic eruptions) and high-energy radiation (X-rays and ultraviolet rays) can generate complex molecules from simpler forms. By 1936, a Russian scientist, Dr. Oparin, had already shown how clusters of molecules can form spherical aggregates called spherules in a liquid medium. A simple membrane developed around the spherules because of surface tension. These spherules behaved somewhat like living cells and may have further developed into self-replicating units containing cell blueprint material – genetic material – that would help form new cells. Much of life's origin is still a matter of speculation but the work of Miller, Fox, Ponnamperuma and Oparin indicates how life could have evolved in the early oceans, under conditions of the early atmosphere.

"Early earth was restless... and matter was shifting and settling in earthquakes."

It seems intuitively obvious that among these early "cells", those that were better at capturing and utilising energy would take over from those that were not as competent. It is also postulated that initially all the energy utilised by these "organisms" came from the

carbohydrates that had been created spontaneously by the electrochemical processes described earlier. It is possible that as the population of carbohydrate-utilising organisms grew, any organism that could produce its own supply of carbohydrate would have a competitive edge over others. This perhaps favoured the development of the chlorophyll molecule, which could capture solar energy to combine carbon dioxide and water to form carbohydrates, and in the process would release free oxygen. The evolution of chlorophyll was the most important event in the history of life on earth because with the advent of free oxygen, ozone could be produced which formed a protective layer around the earth shielding the early organisms from the harmful effects of ultraviolet rays. This also meant that life no longer needed to evolve only in deep oceans where it was naturally protected from ultraviolet light, but could now evolve on the surface of the oceans, from where it moved onto land.

"It was the evolution of chlorophyll that facilitated the radiation of life on earth."

Free oxygen also allowed organisms to break down energy-rich molecules in a manner that was much more efficient than oxygenless chemical transformations. The evolution of the chlorophyll molecule was a critical evolutionary innovation facilitating a radiation of life forms on the earth.

The geological time scale

The history of life on earth is recorded within a geological time scale which is divided hierarchically into eras, periods and epochs, and depends on the evidence of fossils. The eras mark the boundaries of the most significant events. The boundary between the Precambrian and Palaeozoic eras marks the first appearance of hard structures in multicellular animals in the fossil record. The

boundary between the Mesozoic and the Cenozoic eras at the Cretaceous period marks the great mass extinction of the dinosaurs, and the boundary between the Palaeozoic and the Mesozoic at the Permian marks the extinction of most of the marine species. Ninety per cent of all marine species present at that time became extinct in roughly one million years. Time intervals between eras, periods and epochs are not of equal duration and life began to evolve rapidly only about 600 million years ago which probably coincided with the origin of photosynthesising plants.

How did the different geological intervals get their names? The Palaeozoic is the Era of Ancient Life (*palaios* = Greek for ancient; *zoe* = Greek for life), the Mesozoic is the Era of Middle Life (*mesos* = Greek for middle), and the Cenozoic or Cainozoic is the Era of Recent Life (*kainos* = Greek for recent). Periods are usually named after the place (or associated people) at which the first or best representative fossils of that period were found.

"Cambria (Cambrian period) was the old Roman name for Wales in the British Isles."

Cambria (Cambrian period), for example, was the old Roman name for Wales in the British Isles. Perm (Permian period) is a town in the western Ural Mountains in the former Soviet Union, and the Silures (Silurian period) were a primitive people living in Wales.

Sometimes periods derive their names from the distinctive type of fossil deposits laid down at that time. The Carboniferous, for example, refers to the vast carbon deposits laid down in the form of coal, while the Cretaceous refers to vast chalk deposits (*creta* = Latin for chalk) formed by the calcium-filled bodies of marine creatures.

How are fossils and rocks dated? The age of the earth and of fossils is determined by the amount of decay of radioactive isotopes of various elements such as carbon, uranium, thorium and potassium. Isotopes of these elements have a definite time in which they are transformed into their corresponding forms. By estimating the amount of the resultant form present in the rock sample it is possible to calculate the time taken for the transformation and thereby the age of the rock. There are a few more facts to be learned about fossils to understand what they are telling us about the history of life on earth. Firstly, the chances of a plant or animal becoming a fossil depends on where it was or where it was carried to when it died and also of what material it was made. Organisms that lived in shallow seas or lakes and were buried undisturbed in mud or in the ocean floor, or those that had hard calcium-filled body parts are easier to fossilise. Secondly, the chance of discovering fossils depends on how carefully we look for them. For many years the Cambrian period was considered to be the time when multicellular life evolved, and when there was a tremendous explosion of life forms.

" It seems our views on the radiation of early life may have to be modified."

The history of life before the Cambrian was merely referred to as the Precambrian because very few fossils were discovered from this time, most of them of unicellular organisms. Recently, however, Precambrian fossils of many soft-bodied multicellular forms of worms and jellyfish-like creatures have been found at Ediacara in Australia. Our views on the radiation of early life may have to be modified as new fossils are discovered.

Equipped with these basic ideas, we can attempt to understand the story of evolution, adding additional concepts as we go along.

The Precambrian: The early earth was restless and turbulent. Fossils tell us that the first cells (procaryotes like bacteria) appeared about 3.5 billion years ago (one billion years after the earth was born from the sun). More complex types of cells (eucaryotes like algae) first appeared about 1.4 billion years ago. However, the first fossils of multicellular animal life are recorded only about 700 million years ago. These were soft-bodied worms and jellyfish-like creatures. Interestingly, however, none of these multicellular organisms are believed to be ancestral to present-day animals. They appear to have been evolutionary experiments that died out, having failed to establish themselves.

"The fossil record is telling us something... about the history of life on earth."

The Palaeozoic or the Era of Ancient Life

The Cambrian: There were widespread shallow seas creating excellent conditions for fossilisation. There was an explosion of photosynthetic bacteria, algae and fungi indicating that chlorophyll had evolved and free oxygen was available in the atmosphere. As mentioned earlier, this must have contributed to the explosion of life in the Cambrian, which also has abundant fossils of multicellular animals with hard structures. These represent the ancestral forms of most of the invertebrate phyla present today on the earth.

A wonderful fossil-rich area in the Canadian Rocky Mountains called the Burgess Shale has revealed strange creatures that do not even remotely resemble anything present on earth today, creatures with five pairs of eyes, with strange tentacles and protuberances and with even stranger names like *Wiwaxia*.

These science fiction-like creatures too, in all probability, were

failed evolutionary experiments because they have never been found again in any fossil area at any other time in the history of the earth.

The Ordovician: After an initial cold spell the earth started to get warmer. Volcanic activity continued and the Appalachian Mountains were formed in North America. Lime-secreting algae formed limestone reefs in the oceans. The earliest vertebrates appeared in the form of fish with heavily armoured bodies. There was abundant life in the seas.

The Silurian: North America and Europe, which were initially separate continents, came together at the end of this period to form Euramerica. The meeting of the continents resulted in the uplift of mountains such as the Caledonian Mountains in Canada. The climate was becoming warmer, almost desert-like in some places. Jawless fish were very common, but it was during this period that the first jawed fish appeared. The seas were now inhabited by gigantic, predatory sea scorpions. Although seaweeds were common, the first land plants, which were leafless and rootless, appeared.

" The seas were now inhabited by gigantic, predatory sea scorpions."

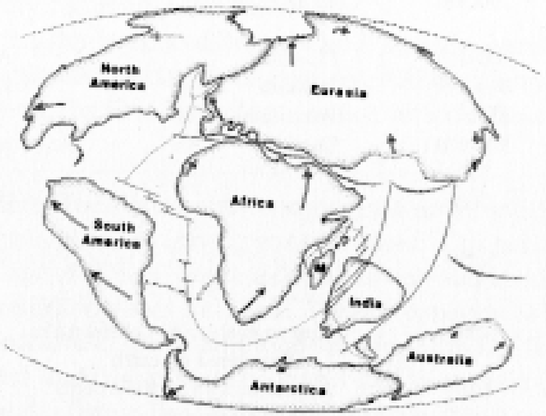
The Devonian: The climate started to get still warmer and drier. The seas began to dry up leaving water in pools. This period is called the "Age of Fishes" because fish were very abundant and diverse in the shallow seas and lakes. The first conquest of land by animals occurred. This was by lobe – or fringe – finned fishes which started to develop more powerful fins to support their weight on land as they pulled themselves from one drying pool to another. This resulted in a primitive amphibian-like form called

Geological time scale and biological evolution

Era	Approx. Age in Millions of Years Before Present	Period	Epoch	Life Form
	Less than 0.01		Recent (Holocene)	
	0.01-2	Quaternary	Pleistocene	Humans
	2			
	2-5		Pliocene	
	5-24		Miocene	
Cenozoic	24-38	Tertiary	Oligocene	Mammals
	38-55		Eocene	
	55-63		Paleocene	
	63			
	63-138	Cretaceous		Flying reptiles, birds
Mesozoic	138-205	Jurassic		
	205-240	Triassic		Dinosaurs
	240			
	240-290	Permian		Reptiles
	290-360	Carboniferous		Insects
				Fossils
Palaeozoic	360-410	Devonian		Amphibians
	410-435	Silurian		Land plants
	435-500	Ordovician		Fish
	500-570	Cambrian		
	570			
	700			Multicelled organisms
	3,400			One-celled organisms
Precambrian	4,000	Approximate age of oldest rocks discovered on earth		
	4,500	Approximate age of the earth and meteorites		

Continental Drift

Laurasia and Gondwanaland at the beginning of the Jurassic (Hollow arrows show continental rotations since the break-up of Pangaea)



The continents at the start of the Tertiary, 65 million years ago

Ichthyostega which had legs and feet derived from fins as well as a fish-like fin on its tail.

Although the amphibians could live on land because they had air-filled lungs, they still retained their ties with aquatic life by laying their jelly-coated eggs in water. On land, plants like mosses and ferns appeared. These land plants still retained traits acquired during their aquatic existence and their male gametes or sperm still had to swim through water to unite with the eggs.

The Carboniferous: The climate was generally warm and very humid with many swamps. However, there was plenty of ice in the southern hemisphere. The amphibians were common and gave rise to the first reptiles by developing a hard-shelled egg that could be laid on land, thus breaking ties with water more completely. A creature like *Seymouria* was probably a link between amphibians and reptiles. Giant winged insects like dragonflies with a wingspan of three-fourths of a metre appeared. There were also giant cockroaches. Changes in the sea levels led to flooding and deposition of layers of sand and mud on the vegetation. This caused incomplete decomposition of the abundant vegetation in the swamps, which led to the formation of peat bogs that were later compacted to form coal. It is these vast deposits of coal in the northern hemisphere which have given this period its name. The first seed-bearing ferns and gymnosperms such as conifers appeared.

"The land plants still retained traits acquired during their aquatic existence."

The Permian: The climate continued to be warm but dry, and icy conditions were still prevalent in the southern hemisphere. Euramerica met together with Asia and Gondwanaland (which

consisted of South America, Africa, India, Australia, Antarctica and New Zealand) to form a single super-continent called Pangaea. The coming together of all these continents resulted in the formation of mountains like the Urals and the Alps. The coal swamps were reduced. Reptiles increased in species diversity and abundance; some species were very strange like the fin-backed *Dimetrodon*. Amphibians were also present. Modern types of insects appeared. There was a mass extinction among fish, coral and other marine creatures. In the face of the drier conditions and reduction of the swamps, many semi-aquatic plants like horsetails and clubmosses went extinct. There was a great increase in conifers. Other gymnosperms like the maidenhair trees or gingkos appeared.

" Shrew-like creatures scurried about... they were the first mammals."

The Mesozoic or the Era of Reptiles

The Triassic: The climate continued to be warm and dry and desert-like conditions prevailed in some areas. The abundant reptiles gave rise to the first dinosaurs (*deinos* = Greek for terrible; *sauros* = Greek for lizard). Some reptiles went back into the seas, and regained fish-like forms to give rise to marine reptiles like the ichthyosaurs (*ikhthus* = Greek for fish). The first mammals evolved from reptiles. They were small shrew-like creatures scurrying about in the undergrowth, probably feeding on insects. Among the gymnosperms the first cycad plants appeared, and conifers and gingkos flourished.

The Jurassic: The super-continent of Pangaea started to fragment and drift apart causing seas to flood over the land. North America, for example, was flooded right through its centre by the formation of the Central Atlantic Ocean. Europe, North America and Asia formed the super-continent of Laurasia. This was the

"Age of Reptiles" because the dinosaurs became very diverse and abundant. Some were vegetarian, others were carnivorous. And they were all of varied shapes and sizes. Some reptiles like the pterosaurs (*pteron* = Greek for wing) developed long wings with which they conquered the Jurassic air. The first bird *Archaeopteryx* evolved from reptiles. This had feathers, toothed jaws and claws on its wings. It probably flew clumsily or used the claws on its wings to haul itself around in the canopies of trees. Among plants, conifers and maidenhair trees were abundant.

The Cretaceous: Continental drift continued, and India had begun to separate from Gondwanaland. The Andes and the Rocky mountains were formed. At the end of the Cretaceous, there were extensive volcanic eruptions giving rise to lava flows which formed the Deccan Traps of India. Although the dinosaurs were dominant initially, they became extinct at the end of this period. Many species of birds and smaller species of mammals were present. The aquatic birds still had teeth like those of *Archaeopteryx*.

"Volcanic eruptions gave rise to lava flows which formed the Deccan Traps of India."

The close connection between some of the continents comprising Gondwanaland at this time caused a peculiar distribution of related primitive flightless birds which today occur only on a few of these continents (the ostrich in Africa, rhea in South America, emu in Australia, the cassowary in Australia and Papua New Guinea, and the kiwi in New Zealand).

The ancestor of these birds probably evolved on Gondwanaland after India split away and then, having entered each separated continent, evolved independently to give rise to the different related types.

Interestingly, New Zealand has no mammals probably because it split off from the super-continent before the ancestral mammals entered it. The first flowering plants or angiosperms appeared, while conifers, cycads and ferns were still common.

The Cenozoic or the Era of Mammals

The Tertiary: The climate fluctuated from cool to warm during this period. Owing to extensive continental drift, there was tremendous mountain-building activity. The Indian plate crashed into the Asian plate to form the Himalaya. The Alps and the Rocky Mountains were uplifted and the Cascade Mountains were formed. Sharks and bony fish were abundant in the oceans. Mammals were very common and radiated extensively, especially herbivores.

> ***New Zealand has no mammals... it split from Gondwanaland before they could enter."***

Initially, there were more browsing animals that fed on a variety of flowering plants, but as grasslands were formed owing to the drier climate, huge herds of grazers and browsers inhabited the grassy plains. Man began his evolution from his ape ancestors during this period.

The Quarternary: The Pleistocene epoch was characterised by four major glaciations within about two million years. These occurred in the northern hemisphere, and vast areas of Europe, Asia and North America were completely ice-bound. Life stirred and revived during the warm inter-glacial periods. In many areas, species went extinct and areas were repopulated with species that managed to survive in climatic refuges. Man continued his evolution. Mammals radiated into different forms, with common mammals like the woolly rhinoceros, the woolly mammoth and the sabre-toothed tiger in the northern hemisphere. In the

Holocene or Recent epoch, the glaciers melted and the climate became warm, to give rise to the climate of today. The large land mammals like the mammoth and the woolly rhinos went extinct.

The age of the dinosaurs

Of all the creatures that once inhabited the earth, probably the most popular and the most exciting were the dinosaurs. Who wouldn't want to study fossils if they were introduced to dinosaurs? These "terrible lizards" roamed the earth for 165 million years, from about 230 million years ago. Although there are about 350 known species, fossils of new dinosaurs are still being discovered. There are two main groups of dinosaurs, those with lizard-like hip bones and those with hips structured like those of birds. The lizard-hipped dinosaurs included the sauropods that were largely herbivores, and the carnivorous theropods. Sauropods like *Brachiosaurus* (24 m long from nose to tip of tail) weighed as much as 50 tons.

> ***"We know of around 350 species... fossils of new dinosaurs are still being discovered."***

Brachiosaurus walked on four legs and with its long neck probably browsed on the topmost branches of the 12 m-high conifers. Another was *Diplodocus* (27 m long) which was probably the longest land animal ever known. When the sauropods dominated the earth, flowering plants had not yet evolved. So, the browsing sauropods had to feed on conifers, cycads and maidenhair trees. The carnivorous theropods walked on their massive hind legs while their front legs were comparatively very small. The largest of these was the famous *Tyrannosaurus rex* (*rex* = king in Latin) who with its massive toothed jaws was a very formidable sight. The theropods probably gave rise to the birds.

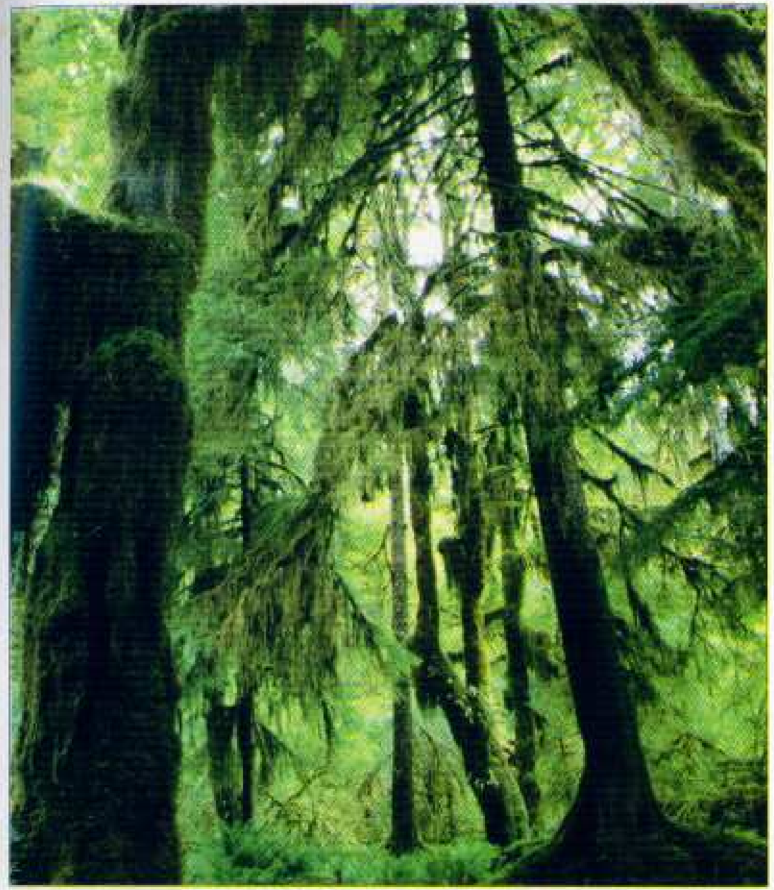
The bird-hipped dinosaurs were strictly vegetarian. They included such strange forms as *Stegosaurus* (8 m long) that had along its back a row of pointed bony plates which may have been used to regulate body temperature. Even stranger was *Triceratops* (10 m long) with a bony frill around its neck or *Parasaurolophus* (11 m long) that had strange crests on its head whose chambers were probably used to amplify and resonate mating calls. The grazing bird-hipped dinosaurs arose in the Cretaceous and fed on flowering plants that had evolved by that time.

> ***"Finding 10,000 dinosaur fossils together... was reminiscent of today's vast wildebeest herds"***

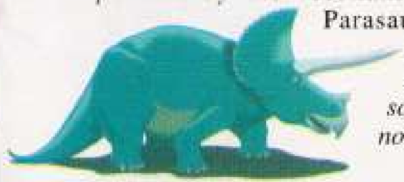
All dinosaurs were not monstrously huge. Some were as small as chickens. It is now believed that the larger dinosaurs were probably cold-blooded while the smaller ones were warm-blooded and able to maintain a constant body temperature like birds and mammals. Why did dinosaurs become so large? Animals usually become large whenever the environment is unpredictable in terms of food supply. The larger an animal, the more fat it can store during times of food abundance. These fat reserves can then help the animal to survive periods of food scarcity.

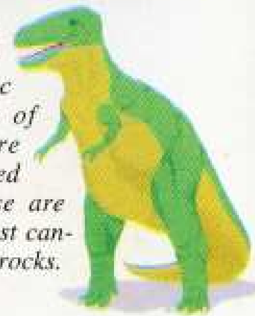
Another reason why animals become huge is when their food supply is widely scattered and when they have to travel long distances to obtain sufficient food to survive. The bigger an animal, the more capable it is of walking or swimming long distances to reach the food source. So, why did dinosaurs become so large? Well, maybe we'll find the answer to this some day.

Some dinosaurs like the ferocious *Tyrannosaurus* may have been solitary, stalking prey singly. However, some of the grazing



There are some questions about dinosaurs that may never be answered: Were they good parents? What were their mating rituals? Was the Jurassic air pierced by the resonant booming calls of Parasaurolophus*? Were they drab coloured or bright? These are some stories that just cannot be written in the rocks.*





The plesiosaur (top) is a Jurassic reptile, the dolphin (middle) is a mammal and the salmon (below) is a fish. All three evolved similar structures such as fins and a streamlined body to cope with life in the water. This process is called convergent evolution (illustrations not to scale).

dinosaurs moved about in herds. In some areas, 10,000 fossil dinosaurs have been found together, somehow reminiscent of the vast herds of wildebeest found today on the East African plains. Possibly just like the wildebeest, these huge dinosaur herds may have come together during great annual migrations. Who can tell? It is all still in the realm of speculation. We know now that some dinosaurs laid their eggs in nests because beautifully preserved fossils of clusters of eggs have been found. Also fossilised sometimes are nests evenly spaced from each other on the ground like those in a colony of nesting gulls. Were dinosaurs good parents? Is it true that they had mating rituals and that the Jurassic air was often pierced with the resonant booming calls of *Parasaurolophus*? Were they drab coloured or bright? We would need to go back in time to answer all these questions because there are some stories that just cannot be written in the rocks.

"The dinosaurs were victims either of an asteroid collision with earth, or of volcano ash."

What happened to the dinosaurs? Why did they suddenly vanish from the earth? The dinosaurs went extinct 65 million years ago. There are currently at least two competing theories to explain this mass extinction in which many other creatures also perished. About 60-70 per cent of all known species of plants and animals went extinct during the same period.

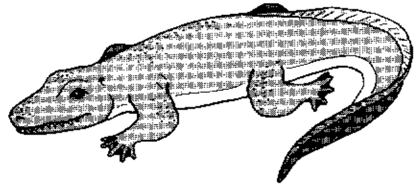
According to one theory formulated by Walter Alvarez and Frank Asaro, a giant meteorite or comet crashed into the earth at that time. This destroyed all life within the vicinity of the impact and created a huge cloud of dust that spread over most of the earth. This cloud blocked out the sunlight, preventing plant photosynthesis. As plants died, all the huge herbivorous dinosaurs dependent on the plants as well as the carnivores dependent on the herbivores also perished. The entire food chain was affected.

The huge dust cloud may have also produced a greenhouse effect causing plants and animals to die of heat. Owing to the high temperatures, oxygen and nitrogen in the atmosphere may have combined to form nitrous oxide giving rise to nitric acid that may have poured down on the earth as deadly acid rain causing further destruction. Evidence to support the asteroid theory is the large concentration of iridium found in deposits at the boundary of the Cretaceous and the Tertiary periods. Iridium is an element normally found in large amounts only in meteorites or comets and normally occurs in only minute quantities on the earth.

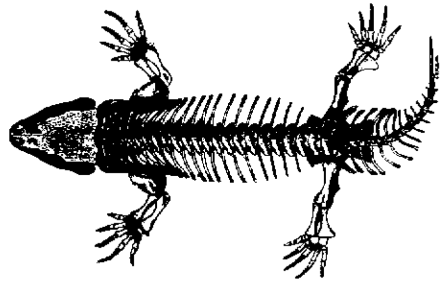
Another theory to explain the dinosaur mass extinction was proposed by Vincent Courtillot who holds massive volcanic eruptions responsible for the event. These eruptions were the same ones that caused the Deccan Traps in India. Let's look at the scenario. India is drifting away from Africa towards Asia, a journey that took 100 million years. As she passed near the island of Reunion in the Indian Ocean, not far from Mauritius, there was a massive outpouring of lava from a volcanic "hot-spot" on the ocean floor and the basaltic lava poured onto the continental crust of India to form the Deccan Traps. So much lava flowed out that in some places the lava layer is as much as 2400 m thick. According to Courtillot, the lava flows may have extended for more than two million square kilometres. Lava flows of such magnitude would probably have caused immense clouds of smoke, sulphur fumes and dust which may have had the same series of effects on the food chain as the impact of an asteroid. Courtillot feels that this theory can apparently explain other mass extinctions also. Another mass extinction which occurred at the end of the Permian, 250 million years ago, may have been caused

"Massive lava flows may have caused immense clouds of smoke, sulphur and dust."

Giant Carboniferous tree fern

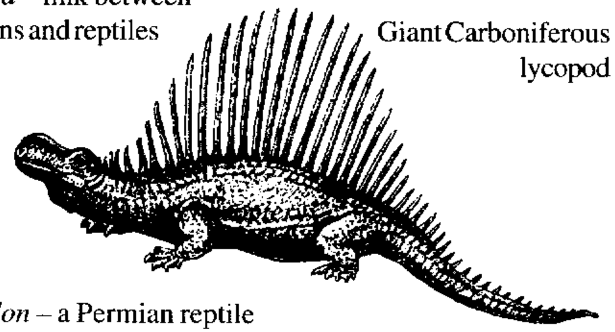


Ichthyostega – link between fish and amphibians



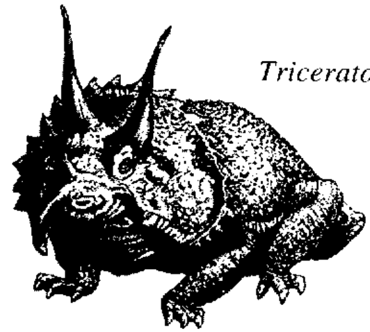
Seymouria – link between amphibians and reptiles

Giant Carboniferous lycopod

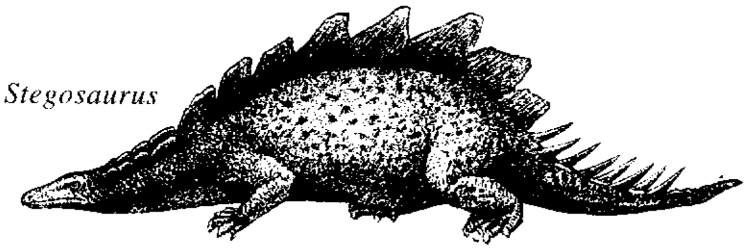


Dimetrodon – a Permian reptile

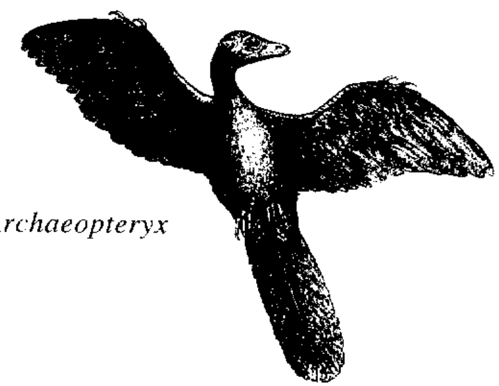
The age of dinosaurs and the rise of birds



Triceratops



Stegosaurus



Archaeopteryx

by volcanic eruptions now represented by the vast basaltic Siberian Traps which are precisely 250 million years old, just before the time when the dinosaurs started to evolve. The massive Permian extinctions may have made way for the dinosaurs who in the Mesozoic came to dominate the earth. Both theories – the impact of an extra-terrestrial object and the volcanic eruptions - are fascinating. Yet, much more research needs to be done before one theory can be chosen over the other.

The rise and fall of the dinosaurs was marked by global mass extinctions probably caused by chance catastrophes. This makes us realise that random chance is such an important factor in the evolution of life. When the dinosaurs were dominant, mammals were small and shrew-like, scurrying about on the forest floor eating insects, earthworms and other soil creatures. Perhaps the small size of mammals at that time prevented them from becoming victims of the global environmental disaster. Perhaps the early mammals survived because they could feed on creatures that could consume the dead and decaying vegetation. Whatever the reason, mammals survived the natural catastrophe, and went on to form the awesome mammoths and mastodons, polar bears and man.

"A huge dust cloud may have been responsible for a greenhouse effect which led to plant deaths."

Convergent versus divergent evolution

We have seen how the lobe-finned fish strengthened their fins to support their weight on land and eventually how these fins were transformed into the legs of amphibians. When the amphibians gave rise to the reptiles, many reptilian species occupied the land. Some, however, re-colonised the water. These species lost their legs and acquired a fish-like anatomy with fins and a powerful lobed tail. Here, the evolutionarily more advanced reptilian-form

converged onto the fish-form to exploit the aquatic medium. A modern day example of such convergence is the similarity between mammalian dolphins and fish. In divergent evolution or adaptive radiation, a single ancestral type gives rise to many diverse forms. An ancient example is the shrew-like insect-eating ancestral mammal that diverged into whales, pandas, kangaroos and giraffes. A modern-day example is the domestic dog that is supposed to have originated from the wolf. Poodles, chihuahuas, and dalmatians are very different from the wolf but they are still dogs. And all breeds of dogs share some genes with their wolf ancestor, besides having some special genes of their own – the unique genes, which make them bulldogs not fox terriers and borzois not salukis.

"Poodles, chihuahuas, and dalmatians are very different but all originated from the wolf."

Living fossils

In 1938, fishermen caught a strange-looking fish off the east coast of South Africa. Ms. Courtenay-Latimer who was in charge of the local museum first examined this fish. She at once realised that it was a very special creature and sent it to the fish experts who confirmed her suspicions and named the fish *Latimeria* in her honour. Why is *Latimeria* so important? Because it is a living fossil – it resembles fossil fish that are 460 million years old. *Latimeria* has remained unchanged for millions of years.

Since 1938, more specimens of *Latimeria* have been caught, all restricted to the Comoro Islands near Madagascar. There are other examples of living fossils and strangely enough, they all occur on islands, in deep oceans and in such places that have remained relatively undisturbed through the ages where perhaps there were few natural predators or other environmental imperatives to encourage them to change.

On some islands of New Zealand there is another living fossil, a spiky lizard called the tuatara by the Maoris. Its closest relatives are fossil reptiles that lived about 170 million years ago during the dinosaur age. It has remained unchanged probably because New Zealand, if you remember, has no natural mammalian predators, except those such as dogs inadvertently introduced into the islands by man. There is also a plant that is a living fossil. The maidenhair tree or *Gingko biloba* evolved during the Permian and continues to live unchanged in a few places in Asia, although it largely survives as an ornamental garden plant today.

"Latimeria resembles fossil fish that swam in ancient oceans 460 million years ago."

The evolution of *Homo sapiens*

Africa is the cradle of mankind. The scene was set in the Miocene of Africa. The forests began giving way to grasslands under the influence of warmer and drier climates. The apes that would give rise to man began to come down from the trees, to adapt to life on the savannas. The savannah grasslands are sparsely dotted with trees, with herds of grazing and browsing hoofed animals. Sometime in the Pliocene between three and four million years ago, this ape lineage split into a line that would ultimately lead to humans and into another leading to chimpanzees and gorillas, which are our nearest living relatives. Incidentally, the orangutan of Malaysia is more closely related to the fossil apes *Ramapithecus* and *Sivapithecus* found in the Siwaliks. The proto-human lineage is called the australopithecine or "southern ape" line (*australis* = Latin for southern; *pithekos* = Greek for ape) after the first fossil of this type found in the Transvaal of South Africa. One of the earliest known australopithecines was later discovered in the Afar region of Ethiopia and has been named *Australopithecus afarensis*. One of these fossils

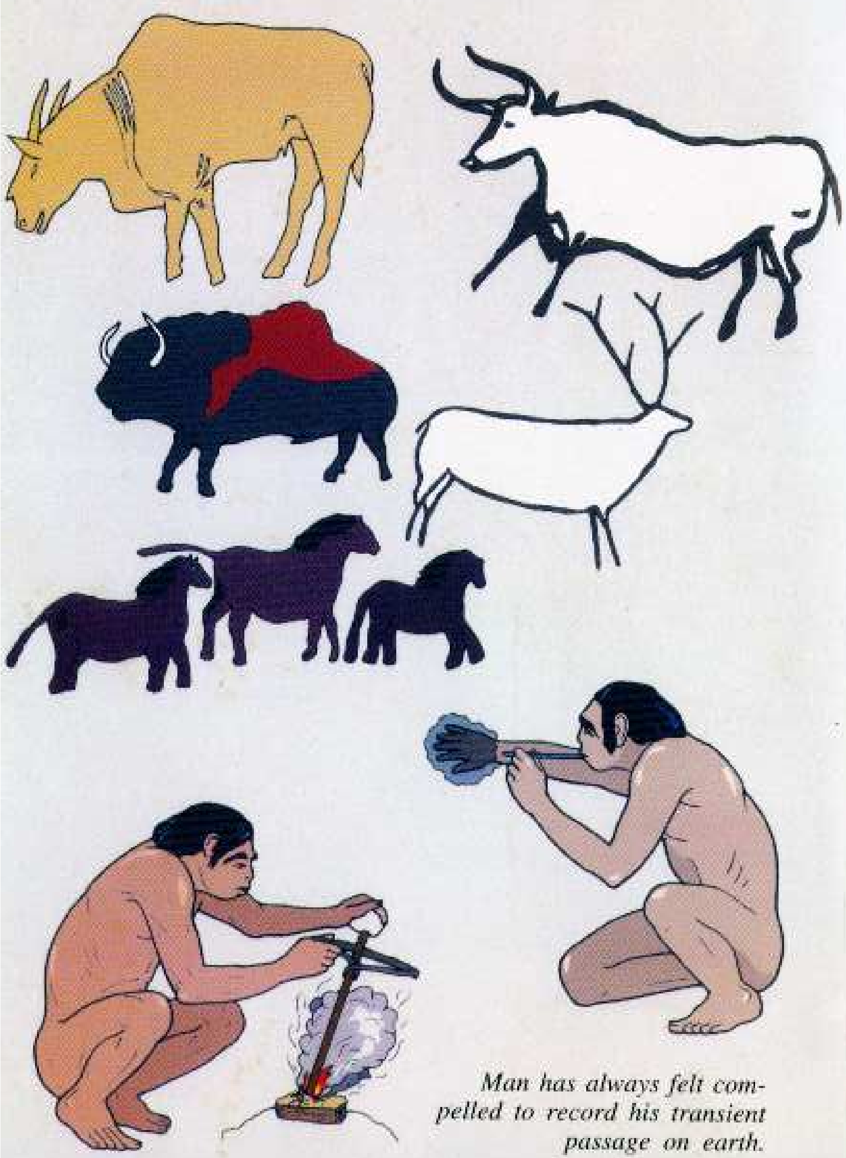
has been popularly named Lucy by her discoverer Donald Johanson. Lucy's line divided into several branches. One branch was called the robust australopithecines, *Australopithecus robustus*, because of the strong and heavy structure of their bones. They became extinct one million years ago. About two million years ago in the Pleistocene, another branch led to a line of hominids who were capable of making stone tools and were, therefore, called *Homo habilis* ("handy man"). This lineage gave rise to *Homo erectus*, so called because of his relatively erect fully bipedal posture. *Homo erectus* later discovered the use of fire and made more advanced stone tools than *Homo habilis*. *Homo erectus* later spread from Africa into Asia. Remember that this was the time of the Pleistocene glaciations when most of the northern hemisphere was ice-bound, when the waters of the seas were locked up in ice, leaving many areas of land exposed. There were probably land bridges in the seas between Africa and Asia via the current Middle East. *Homo erectus* fossils have been found in Asia also in the form of Java man in 1890 and Peking man in 1926. This line then gave rise to an offshoot called Neanderthal man after the Neander valley in Germany where their fossils was first found in 1856 in a limestone quarry.

"One of these fossils was named Lucy by her discoverer Donald Johanson."

Neanderthal man was a short, thickset man with heavy brows. He lived during Pleistocene inter-glacials in Europe, North Africa, the Middle East, Central Asia and China. He hunted mammoths, woolly rhinos, and cave bears with hand axes and wooden spears. He was probably cannibalistic and incapable of speech. He became extinct about 30,000 years ago. No one knows exactly why this happened although various theories have been proposed. One theory attributes his extinction to conflicts with a more

The evolution of life on earth started in the great oceans. This process continues to unfold. The study of life before man is crucial to our understanding of the world in which we live.

Episodes in earth's history frozen in layered basalt at Mahabaleshwar in the Western Ghats.



Man has always felt compelled to record his transient passage on earth.

advanced hominid called Cro-Magnon man, another feels it may have been caused by disease or drastic climatic changes. Whatever the reason may be, Neanderthal man died out and the *Homo erectus* line gave rise to slender Cro-Magnon man named after the cave near the village of Les Eyzies in France where the fossils were first found. Cro-Magnon man was our direct ancestor. With a great sense of art and beauty he covered the walls of several caves in France with nearly life-size paintings of the animals he hunted which were great herds of bison and deer. He probably fought and defeated Neanderthal man and established our species worldwide.

"Neanderthal man hunted mammoths, woolly rhinos and cave bears with hand axes."

By the beginning of the 20th century, so many fossils of early man had been found that it was evident that there was no definite ladder-like progression towards modern man in the sense of one ape-like form clearly giving rise to another which ultimately led to man. The history of man has been more like a bush with many side branches representing evolutionary experiments that went extinct. We have been named *Homo sapiens* (*sapiens* = Latin for wise), but are we worthy of being called wise men? Are we capable of looking after this planet that we have inherited from the first stirrings of life in the primitive oceans?

Creation or Evolution?

Then was not non-existent nor existent:
there was no realm of air, no sky beyond it.
What covered in, and where? And what gave shelter?
Was water there, unfathomed depth of water? ....
Who verily knows and who can here declare it,
whence it was born and whence comes this creation?

The Gods are later than this world's production.
Who knows then whence it first came into being?
He, the first origin of this creation,
whether he formed it all or did not form it,
Whose eye controls this world in highest heaven,
he verily knows it, or perhaps he knows not.

Creation hymn from the Rig-veda

These beautiful words written about 4,000 years ago evoke the eternal mystery of the world's existence. In the seventeenth century, calculations made by Archbishop James Ussher and Dr. John Lightfoot, proclaimed that according to the Old Testament of the Bible, the earth had been created on the 23rd of October, 4004 B.C. at 9 a.m. The very first book of the Bible, the Book of Genesis, had also stated that the earth and all the creatures on it including man were created in six days. The Creator rested on the seventh day after the labour of his efforts. Man was believed to have been created in the likeness of God. This belief in the special creation of man and of all life forms greatly influenced the thinking of natural scientists. The major difficulty that the doctrine of special creation had to overcome was the existence of fossils. One way to explain fossils was by the Flood Theory in which all extinct creatures were supposed to be those that perished in the Great Flood which only Noah and his ark survived. However, if the Flood was a single event, it could not explain layers of fossils laid down in sedimentary rock with the fossils in the later rocks clearly related to those in the earlier ones. It certainly could not explain how fossils of animals living before the Flood were found.

"Cro-Magnon probably fought and defeated Neanderthal man and established our species."

Baron Georges Cuvier (1769-1832) who was one of the world's greatest comparative anatomists attempted to find a way out of this dilemma by proposing the Catastrophe Theory. This theory holds that the earth was supposed to have undergone a series of catastrophes, each catastrophe destroying all life on earth. At the end of each extinction, new life consisting of more advanced forms was supposed to have been created by God. There were supposed to have been at least 32 catastrophes in the history of the earth, Noah's Flood being only one of them. In order to give sufficient time for these changes to occur, the earth was estimated to be several thousand years older than the early proclamations of Archbishop Ussher. One of the first people to be convinced that the earth was indeed much older was James Hutton (1726-1797). Hutton, after studying geological formations, felt that the physical forces of erosion and uplift that had shaped the earth had acted in a more or less continuous manner, rather than in abrupt catastrophes. He founded the view of Uniformitarianism in which the gradual forces of erosion and restoration continue to change the earth even today. This view was taken up and championed by Charles Lyell (1797-1875) whose geologically oriented wanderings in Europe resulted in the most important book on geology and earth history ever written. In his *Principles of Geology*, Lyell argued persuasively for the belief in the great antiquity of the earth and for the view that geological forces acting on the earth today could explain all the observed geological formations. Lyell also believed that species continued to become extinct in a regular, uniform manner. He could not, however, explain the periodic appearance of new life forms, a task that he was content to leave to the Creator. A little earlier than Lyell, Chevalier de Lamarck in France (1744-

"Noah's flood was supposed to be one of 32 catastrophes in the history of the earth."

1829), propounded the view that life proceeds in a ladder-like manner, becoming progressively more complex, and that animals and plants respond to changes in their environment by acquiring suitable adaptive characteristics. He believed that any changes acquired by the animal during its lifetime were passed on to its offspring. An oft-cited example of this theory is a blacksmith developing bulging arm muscles as a result of lifting heavy iron hammers, and then passing on similar over-developed arm musculature to his children. This theory came to be called evolution via the inheritance of acquired characters which was sinceproved baseless.

The advent of Charles Darwin

"It is often said that serendipity plays a very important part in scientific discovery."

This was the intellectual climate when Charles Darwin (1809-1882) boarded the H.M.S. Beagle in 1831, on the start of a five-year voyage around the world. He was hired as the ship's naturalist to record the diversity of plants and animals found in different regions. Although the ship's commander Captain FitzRoy did not tell this to Darwin, he privately hoped that Darwin would find evidence on the journey to substantiate the Book of Genesis and the validity of the Great Flood. Darwin packed Lyell's *Principles of Geology* into his luggage and meticulously noted and preserved hundreds of plant and animal specimens as well as fossils during the long voyage. It is often said that serendipity plays a very important part in scientific discovery. So it was with Darwin. Towards nearly the end of the Beagle's voyage, the ship reached the Galapagos Islands (*galapagos* = Spanish for giant tortoise). These are a cluster of small volcanic islands belonging to Ecuador and are situated on the equator in the Pacific Ocean about 1,000 km off the west coast of South

America. These islands arose from the sea about one or two million years ago, and being devoid of life at birth, must have been colonised by plants and animals which came from South America by crossing the intervening ocean.

Darwin was struck by the fact that although the islands were only about 50 to 100 km. apart from each other, different forms of the same type of organism occupied each island. Each island had its own type of giant tortoise and it was possible to tell from which island a tortoise came from by merely looking at its shell. Each island also had its own type of thrush-sized, predatory mocking-bird. The most striking were the finches, which are small sparrow-sized birds. On the South American mainland where the finches must have come from, they are small ground-dwelling seed-eating birds with medium-sized bills. However, on the Galapagos, most islands had their own type of finch, and some islands had several different types living together. Some had thick heavy bills for cracking open nuts, others had slender warbler-like bills with which they caught insects, still another one called the cactus finch had learned to use a cactus spine to probe into holes for insects just as a woodpecker uses its sharply-pointed bill and long tongue.

"Darwin carefully noted the strange island-to-island variation in species."

Darwin carefully noted all this strange island-to-island variation in the tortoises, mockingbirds and finches. He was only to realise the significance of all this for evolution in 1838, three years after the voyage had ended. Again, chance had an important role to play in the discovery. Darwin had read Adam Smith's writings on how competition between industries in a capitalist society results in better products because the consumer chooses the better products over the ones of lower quality. He had also just read

Thomas Malthus' *Essay on the Principles of Population*, in which Malthus pointed out that the human population would increase indefinitely in geometric progression (i.e. 2, 4, 8, 16, 32, 64,...) unless it were limited by natural checks such as food supply. One day in 1838, while travelling in a coach, Darwin suddenly realised how the combined views of Adam Smith and Malthus could explain how species could change and how new species could be derived from earlier ones. Darwin was a marvellous writer, so let him now speak for himself. "..can we doubt (remembering that many more individuals are born than can possibly survive) that individuals having any advantage, however slight, over others, would have the best chance of surviving and of procreating their kind? ...This preservation of favourable individual differences and variations, and the destruction of those which are injurious, I have called Natural Selection, or the Survival of the Fittest. Variations neither useful nor injurious would not be affected by natural selection. .... The theory of natural selection is grounded on the belief that each new variety, and ultimately each new species, is produced and maintained by having some advantage over those with which it comes into competition; and the consequent extinction of the less-favoured forms almost inevitably follows."

"Man must have arisen from the apes which are the creatures most closely related to us."

Darwin's discovery of evolution by natural selection led him to realise that just as the different species of finch, mockingbird, or tortoise adapted to their own particular environment, and in turn gave rise to new species, so also, man must have risen from the apes which are the most closely related creatures. As this would destroy the belief in the special creation of man, Darwin brooded quietly over his theory for nearly twenty years without making it

public. Only when he realised that the same discovery had just been made by another naturalist, Alfred Russell Wallace, was he was compelled to write *On the Origin of Species* (from which the earlier quotation was taken). This was the most famous of all books in the last century, in which he expounded the theory of evolution by natural selection.

Although, Darwin knew that his theory of natural selection would only work if the variation between individuals, on which natural selection acts, could be passed on from generation to generation, neither he nor anyone at that time knew anything about the mechanisms of inheritance. Darwin proposed the theory of pangenesis in which tiny bits of each part of the adult body were supposed to be contained within the sperm and egg, and a union of egg with sperm was supposed to give rise to a fully formed human with paternal and maternal characters.

"This... I have called Natural Selection or the Survival of the Fittest..."

Charles Darwin

Then in 1866, Gregor Mendel, an Austrian monk, was conducting breeding experiments with garden peas, and found that each variation in a character such as shape or colour of the pea was controlled by a separate heritable unit that could be passed from generation to generation. Later in 1886, Hugo de Vries discovered that these units called genes could change or mutate. H.J. Muller bombarded fruit flies with X-rays in 1927 and showed that the rate of mutation, as determined by the different types and number of aberrant offspring produced, was directly related to the amount of X-ray radiation received.

The marriage of Darwinism and the developing science of genetics was called Neo-Darwinism (or new Darwinism), and the most thrilling event in the history of genetics took place in 1953

(the same year as Stanley Miller's experiments on the origin of life), when the chemical structure of the genetic material was discovered by James Watson and Francis Crick. These scientists won the Nobel prize for the discovery that genes are made of deoxyribonucleic acid or DNA which occurs as a double helix in which two strands of substances called nucleotides are wound together in a helical manner. Each nucleotide consists of a compound called a nucleotide base, a sugar called deoxyribose and a phosphate molecule. There are four bases, namely adenine (A), guanine (G), thymine (T), and cytosine (C).

"A species is a collection of similar individuals that can breed with each other."

Genes are the code or blueprint for the formation of proteins. Some proteins form enzymes which help to make the other important body molecules – the carbohydrates and fats. Since proteins are made of amino acids, genes consist of codes for amino acids which are arranged in different ways to produce the different proteins. A set of three nucleotide bases corresponds to a code for a single amino acid. Therefore, the code is written in triplets. Since there are four nucleotide bases, there are 64 possible triplet combinations (4^3=64). Some amino acids are coded for by more than one kind of triplet and the beginning and end of each gene is recognised by start and stop codes. Like any other code, such as Morse code for example, an error in the code can result in a garbled message. In this case it would result in a defective protein.

Mutations at the gene level occur when mistakes are made in copying the genes when eggs and sperm are produced, resulting in an alteration in some character in the offspring. However, as we read Darwin's words earlier, all mutations are not bad or injurious. How otherwise would better adapted individuals be produced? Also, some mutations may be neutral, that is, there may be no selective advantage between one mutant form and the other. Such mutations would not be acted upon by natural selection. Mutations do not occur only at the gene level. They can also occur at the level of the chromosomes which are the larger units into which the double helix is organised. Sometimes, bits of chromosomes can be broken off or become attached to other chromosomes during egg or sperm production causing major alterations in the arrangement or number of genes. Thus, changes in individual form occur by mutations in the genetic material which create heritable variation for natural selection to act upon.

"Mutations at the gene level occur when mistakes are made in copying the genes."

With this background, can we now begin to understand how new species can form? In the first place, what exactly is a species? In the conventionally accepted definition, a species consists of a collection of similar individuals which can breed with each other to produce fertile offspring. Individuals of two species cannot successfully breed together and are reproductively isolated from each other. Tigers, for example, can mate with lions under artificial conditions to produce tiglions but tiglions cannot breed to give rise to more tiglions because they are sterile.

The most popularly accepted view of species formation is via geographical isolation. Suppose a group of individuals of a single species is suddenly divided by a physical barrier like a mountain or lake into two populations which cannot breed with each other because they are geographically isolated. Let us also suppose that during the time these populations are isolated, each population evolves slightly differently from the other because of chance events or because of slightly different environments. In the course

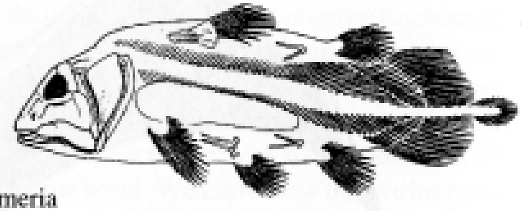
of time each of these populations may acquire characteristics, by mutation and selective breeding of individuals, that make them incompatible and reproductively isolated from each other. This will result in two species, where formerly there was only one ancestral form.

Sometimes two populations of the same species may evolve differently because of isolation and consequently look different from each other. Yet they are not reproductively isolated and can still breed successfully if they come again into contact. Such populations are said to belong to different sub-species of the same species. The variation between the Galapagos finches, tortoises and mockingbirds may now be explained. Although all the tortoises belong to the same species, on some of the drier islands where cactus was common, they developed long necks to feed on the tall cactus, while in the more moist islands their necks remained shorter to feed on grass and other short plants. They also differed in size and shell shape probably because of the effects of isolation. The finches not only eat seeds like their South American ancestors but also behave like insect-feeding warblers and woodpeckers. This is because there are no warblers and woodpeckers on the islands.

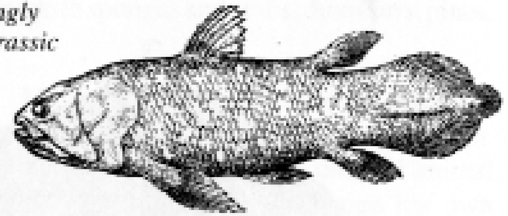
"Man is an animal, and like the others, is subject to the power of natural selection."

Somehow these groups of birds did not reach the Galapagos from the mainland. So the finches were able to expand into the feeding roles of these other types of birds and their forms changed accordingly. In the Galapagos finches, the original ancestral species probably remained intact while the derived species changed their forms. Sometimes, however, the ancestral species itself may change if it is divided into two or more populations

Living Fossils



The coelacanth, Latimeria *seen below, is strikingly similar to a fossil Jurassic fish seen above.*



The leaves and seeds of Gingko biloba, *or the maidenhair tree*

An extinct pterodactyl (top) and today's bat (centre) and bird (bottom) found similar, yet different ways of making wings.

which inhabit different types of environments in which different types of natural selection pressures are present.

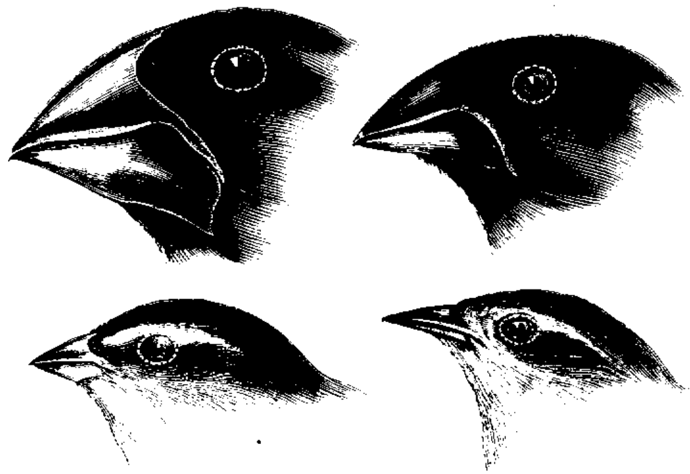
The Galapagos are also called the Encantadas or the Enchanted Islands. In retrospect, this name has profound significance because of the effect these islands had on Darwin, and consequently on our perception of our place in the universe. Darwin gave us a simple and yet elegant theory which has connected all life together with the same bond. We know now that we humans share common origins with sponges and crabs, dinosaurs, pines, roses, and monkeys.

"Isolation can cause two populations of the same species to evolve differently."

Man is an animal and like other creatures is subject to the power of natural selection. However, man is a very unusual animal because he is able to change his own environment in a way and on a scale of magnitude that no other animal has ever done before or may ever be able to accomplish. With the development of modern technology, man is capable of such feats as bulldozing whole mountains within days. He can destroy millions of acres of forest teeming with a myriad other life forms, contaminate vast areas of the earth with nuclear radiation and pollute whole seas with oil spills, thus destroying all life on coral reefs. Man is making the environment too harmful even for himself to survive. His population is exploding because of better medical facilities and more food production. What natural checks and balances can there be? Man is currently battling one serious threat, the AIDS virus, which by the year 2,000 will have caused the death of countless numbers of people. If man has been successful in curbing so many other killer organisms, what is so special about AIDS? The simple fact is that the AIDS virus is evolving by

mutation at a rate faster than the rate of development of suitable medical technology to control it. Will the AIDS virus win the evolutionary race over man? Will man be able to survive the impending environmental, population and medical disasters? Will he be able to live up to his name of the "wise man" of the planet? Perhaps he may, if he stops to remember that the earth is his only home and that he is only an animal subject to the powerful forces of nature.

We have read the history of earlier life in the rocks. But will there be anyone that looks like us to read our story?



Variation in beak shape and size in a few of Darwin's finches from the Galapagos

Annexure

In this extract from "The Descent of Man and Selection in Relation to Sex", 1871, Darwin explains the concept of sexual selection and compares it with natural selection as an evolutionary force. Why are the males of some species showier than the females? How do females select their mates? What balance of forces determines the size of antlers in stags? Such questions can be addressed within the arena of sexual selection.

PRINCIPLES OF SEXUAL SELECTION

WITH animals which have their sexes separated, the males necessarily differ from the females in their organs of reproduction; and these are the primary sexual characters. But the sexes often differ in what Hunter has called secondary sexual characters, which are not directly connected with the act of reproduction; for instance, the male possesses certain organs of sense or locomotion, of which the female is quite destitute, or has them more highly-developed, in order that he may readily find or reach her; or again the male has special organs of prehension for holding her securely. These latter organs, of infinitely diversified kinds, graduate into those which are commonly ranked as primary, and in some cases can hardly be distinguished from them; we see instances of this in the complex appendages at the apex of the abdomen in male insects. Unless indeed we confine the term "primary" to the reproductive glands, it is scarcely possible to decide which ought to be called primary and which secondary.

The female often differs from the male in having organs for the nourishment or protection of her young, such as the mammary glands of mammals, and the abdominal sacks of the marsupials. In some few cases also the male possesses similar organs, which are wanting in the female, such as the receptacles for the ova in certain male fishes, and those temporarily developed in certain male frogs. The females of most bees are provided with a special

apparatus for collecting and carrying pollen, and their ovipositor is modified into a sting for the defense of the larvae and the community. Many similar cases could be given, but they do not here concern us. There are, however, other sexual differences quite unconnected with the primary reproductive organs, and it is with these that we are more especially concerned such as the greater size, strength, and pugnacity of the male, his weapons of offence or means of defence against rivals, his gaudy colouring and various ornaments, his power of song, and other such characters.

Besides the primary and secondary sexual differences, such as the foregoing, the males and females of some animals differ in structures related to different habits of life, and not at all, or only indirectly, to the reproductive functions. Thus the females of certain flies (Culicidae and Tabanidae) are blood-suckers, whilst the males, living on flowers, have mouths destitute of mandibles. The males of certain moths and of some crustaceans (e. g. Tanais) have imperfect, closed mouths, and cannot feed. The complemental males of certain cirripedes live like epiphytic plants either on the female or the hermaphrodite form, and are destitute of a mouth and of prehensile limbs. In these cases it is the male which has been modified, and has lost certain important organs, which the females possess. In other cases it is the female which has lost such parts; for instance, the female glow-worm is destitute of wings, as also are many female moths, some of which never leave their cocoons. Many female parasitic crustaceans have lost their natatory legs. In some weevil-beetles (Curculionidae) there is a great difference between the male and female in the length of the rostrum or snout; but the meaning of this and of many analogous differences, is not at all understood. Differences of structure between the two sexes in relation to different habits of life are generally confined to the lower animals; but with some few birds the beak of the male differs from that of the female. In the Huia of New Zealand the difference is wonderfully great, and we hear from Dr. Buller that the male uses his strong beak in chiselling the larvae of insects out of decayed wood, whilst the

female probes the softer parts with her far longer, much curved and pliant beak: and thus they mutually aid each other. In most cases, differences of structure between the sexes are more or less directly connected with the propagation of the species: thus a female, which has to nourish a multitude of ova, requires more food than the male, and consequently requires special means for procuring it. A male animal, which lives for a very short time, might lose its organs for procuring food through disuse, without detriment; but he would retain his locomotive organs in a perfect state, so that he might reach the female. The female, on the other hand, might safely lose her organs for flying, swimming, or walking, if she gradually acquired habits which rendered such powers useless.

We are, however, here concerned only with sexual selection. This depends on the advantage which certain individuals have over others of the same sex and species solely in respect of reproduction. When, as in the cases above mentioned, the two sexes differ in structure in relation to different habits of life, they have no doubt been modified through natural selection, and by inheritance, limited to one and the same sex. So again the primary sexual organs, and those for nourishing or protecting the young, come under the same influence; for those individuals which generated or nourished their offspring best, would leave, *caeteris paribus*, the greatest number to inherit their superiority; whilst those which generated or nourished their offspring badly, would leave but few to inherit their weaker powers. As the male has to find the female, he requires organs of sense and locomotion, but if these organs are necessary for the other purposes of life, as is generally the case, they will have been developed through natural selection. When the male has found the female, he sometimes absolutely requires prehensile organs to hold her; thus Dr. Wallace informs me that the males of certain moths cannot unite with the females if their tarsi or feet are broken. The males of many oceanic crustaceans, when adult, have their legs and antennae modified in an extraordinary manner for the prehension of the female; hence we may suspect that it is because these animals are washed about by the waves of the open sea, that they require these organs in

order to propagate their kind, and if so, their development has been the result of ordinary or natural selection. Some animals extremely low in the scale have been modified for this same purpose; thus the males of certain parasitic worms, when fully grown, have the lower surface of the terminal part of their bodies roughened like a rasp, and with this they coil round and permanently hold the females.

When the two sexes follow exactly the same habits of life, and the male has the sensory or locomotive organs more highly developed than those of the female, it may be that the perfection of these is indispensable to the male for finding the female; but in the vast majority of cases, they serve only to give one male an advantage over another, for with sufficient time, the less well-endowed males would succeed in pairing with the females; and judging from the structure of the female, they would be in all other respects equally well adapted for their ordinary habits of life. Since in such cases the males have acquired their present structure, not from being better fitted to survive in the struggle for existence, but from having gained an advantage over other males, and from having transmitted this advantage to their male offspring alone, sexual selection must here have come into action. It was the importance of this distinction which led me to designate this form of selection as Sexual Selection. So again, if the chief service rendered to the male by his prehensile organs is to prevent the escape of the female before the arrival of other males, or when assaulted by them, these organs will have been perfected through sexual selection, that is by the advantage acquired by certain individuals over their rivals. But in most cases of this kind it is impossible to distinguish between the effects of natural and sexual selection. Whole chapters could be filled with details on the differences between the sexes in their sensory, locomotive, and prehensile organs. As, however, these structures are not more interesting than others adapted for the ordinary purposes of life, I shall pass them over almost entirely, giving only a few instances under each class.

There are many other structures and instincts which must have been developed through sexual selection- such as the weapons of offence and the means of defence- of the males for fighting with and driving away their rivals- their courage and pugnacity- their various ornaments- their contrivances for producing vocal or instrumental music- and their glands for emitting odours, most of these latter structures serving only to allure or excite the female. It is clear that these characters are the result of sexual and not of ordinary selection, since unarmed, unornamented, or unattractive males would succeed equally well in the battle for life and in leaving a numerous progeny, but for the presence of better endowed males. We may infer that this would be the case, because the females, which are unarmed and unornamented, are able to survive and procreate their kind.... When we behold two males fighting for the possession of the female, or several male birds displaying their gorgeous plumage, and performing strange antics before an assembled body of females, we cannot doubt that, though led by instinct, they know what they are about, and consciously exert their mental and bodily powers.

Just as man can improve the breeds of his game-cocks by the selection of those birds which are victorious in the cock-pit, so it appears that the strongest and most vigorous males, or those provided with the best weapons, have prevailed under nature, and have led to the improvement of the natural breed or species. A slight degree of variability leading to some advantage, however slight, in reiterated deadly contests would suffice for the work of sexual selection; and it is certain that secondary sexual characters are eminently variable. Just as man can give beauty, according to his standard of taste, to his male poultry, or more strictly can modify the beauty originally acquired by the parent species, can give to the Sebright bantam a new and elegant plumage, an erect and peculiar carriage- so it appears that female birds in a state of nature, have by a long selection of the more attractive males, added to their beauty or other attractive qualities. No doubt this implies powers of discrimination and taste on the part of the female which will at first appear extremely improbable; but by the facts to be adduced hereafter, I hope to be able to shew that the females actually have these powers. When, however, it is said that the lower animals have a sense of beauty, it must not be supposed that such sense is comparable with that of a cultivated man, with his multiform and complex associated ideas

From our ignorance on several points, the precise manner in which sexual selections acts is somewhat uncertain.... It is certain that amongst almost all animals there is a struggle between the males for the possession of the female. This fact is so notorious that it would be superfluous to give instances.

Hence the females have the opportunity of selecting one out of several males, on the supposition that their mental capacity suffices for the exertion of a choice. In many cases special circumstances tend to make the struggle between the males particularly severe. Thus the males of our migratory birds generally arrive at their places of breeding before the females, so that many males are ready to contend for each female.... The majority of the male salmon in our rivers, on coming up from the sea, are ready to breed before the females. So it appears to be with frogs and toads. Throughout the great class of insects the males almost always are the first to emerge from the pupal state, so that they generally abound for a time before any females can be seen. The cause of this difference between the males and females in their periods of arrival and maturity is sufficiently obvious. Those males which annually first migrated into any country, or which in the spring were first ready to breed, or were the most eager, would leave the largest number of offspring; and these would tend to inherit similar instincts and constitutions. It must be borne in mind that it would have been impossible to change very materially the time of sexual maturity in the females, without at the same time interfering with the period of the production of the young- a period which must be determined by the seasons of the year. On the whole there can be no doubt that with almost all animals, in which the sexes are separate, there is a constantly recurrent struggle between the males for the possession of the females.

Our difficulty in regard to sexual selection lies in understanding how it is that the males which conquer other males, or those which prove the most attractive to the females, leave a greater number of offspring to inherit their superiority than their beaten and less attractive rivals. Unless this result does follow, the characters which give to certain males an advantage over others, could not be perfected and

augmented through sexual selection. When the sexes exist in exactly equal numbers, the worst-endowed males will (except where polygamy prevails), ultimately find females, and leave as many offspring, as well fitted for their general habits of life, as the best-endowed males. From various facts and considerations, I formerly inferred that with most animals, in which secondary sexual characters are well developed, the males considerably exceeded the females in number; but this is not by any means always true. If the males were to the females as two to one, or as three to two, or even in a somewhat lower ratio, the whole affair would be simple; for the better-armed or more attractive males would leave the largest number of offspring. But after investigating, as far as possible, the numerical proportion of the sexes, I do not believe that any great inequality in number commonly exists. In most cases sexual selection appears to have been effective in the following manner.

Let us take any species, a bird for instance, and divide the females inhabiting a district into two equal bodies, the one consisting of the more vigorous and better-nourished individuals, and the other of the less vigorous and healthy. The former, there can be little doubt, would be ready to breed in the spring before the others; and this is the opinion of Mr. Jenner Weir, who has carefully attended to the habits of birds during many years. There can also be no doubt that the most vigorous, best-nourished and earliest breeders would on an average succeed in rearing the largest number of fine offspring. The males, as we have seen, are generally ready to breed before the females; the strongest, and with some species the best armed of the males, drive away the weaker; and the former would then unite with the more vigorous and better-nourished females, because they are the first to breed. Such vigorous pairs would surely rear a larger number of offspring than the retarded females, which would be compelled to unite with the conquered and less powerful males, supposing the sexes to be numerically equal; and this is all that is wanted to add, in the course of successive generations, to the size, strength and courage of the males, or to improve their weapons.

But in very many cases the males which conquer their rivals, do not obtain possession of the females, independently of the choice of the

latter. The courtship of animals is by no means so simple and short an affair as might be thought. The females are most excited by, or prefer pairing with, the more ornamented males, or those which are the best songsters, or play the best antics; but it is obviously probable that they would at the same time prefer the more vigorous and lively males, and this has in some cases been confirmed by actual observation. Thus the more vigorous females, which are the first to breed, will have the choice of many males; and though they may not always select the strongest or best armed, they will select those which are vigorous and well armed, and in other respects the most attractive. Both sexes, therefore, of such early pairs would as above explained, have an advantage over others in rearing offspring; and this apparently has sufficed during a long course of generations to add not only to the strength and fighting powers of the males, but likewise to their various ornaments or other attractions.

In the converse and much rarer case of the males selecting particular females, it is plain that those which were the most vigorous and had conquered others, would have the freest choice; and it is almost certain that they would select vigorous as well as attractive females. Such pairs would have an advantage in rearing offspring, more especially if the male had the power to defend the female during the pairing-season as occurs with some of the higher animals, or aided her in providing for the young. The same principles would apply if each sex preferred and selected certain individuals of the opposite sex; supposing that they selected not only the more attractive, but likewise the more vigorous individuals.

Sexual selection acts in a less rigorous manner than natural selection. The latter produces its effects by the life or death at all ages of the more or less successful individuals. Death, indeed, not rarely ensues from the conflicts of rival males. But generally the less successful male merely fails to obtain a female, or obtains a retarded and less vigorous female later in the season, or, if polygamous, obtains fewer females; so that they leave fewer, less vigorous, or no offspring. In regard to structures acquired through ordinary or natural selection, there is in most cases, as long as the conditions of life remain the same, a limit to the amount of advantageous modification in relation to certain special purposes; but in regard to structures adapted to make one male victorious over another, either in fighting or in charming the female, there is no definite limit to the amount of advantageous modification; so that as long as the proper variations arise the work of sexual selection will go on. This circumstance may partly account for the frequent and extraordinary amount of variability presented by secondary sexual characters. Nevertheless, natural selection will determine that such characters shall not be acquired by the victorious males, if they would be highly injurious, either by expending too much of their vital powers, or by exposing them to any great danger. The development, however, of certain structures – of the horns, for instance, in certain stags – has been carried to a wonderful extreme; and in some cases to an extreme which, as far as the general conditions of life are concerned, must be slightly injurious to the male. From this fact we learn that the advantages which favoured males derive from conquering other males in battle or courtship, and thus leaving a numerous progeny, are in the long run greater than those derived from rather more perfect adaptation to their conditions of life. We shall further see, and it could never have been anticipated, that the power to charm the female has sometimes been more important than the power to conquer other males in battle.

GLOSSARY

acid rain: emission of polluting gases such as sulphur dioxide (SO_2) and nitrogen oxides (NO_x) which when reacting with water vapour in the atmosphere to form sulphuric and nitric acids (H_2SO_4, HNO_3), acidify the rain (pH C 5.0).

amino acid: a class of organic compounds which link together to form proteins; each contains at least one amino group (-NH_2) and at least one carboxyl group (-COOH).

angiosperm: flowering plant bearing ovules within a closed organ called the ovary. The ovary forms the fruit and the ovules, if fertilised, form the seeds.

browser: a herbivorous animal feeding on woody twigs or shoots of shrubs, trees or woody vines. cf. grazer

carbohydrate: an organic compound consisting of carbon, hydrogen and oxygen, e.g. sugar and starch.

cold-blooded: incapable of maintaining constant body temperature, e.g. fish, reptiles, amphibians. cf. warm-blooded.

continental plate: the upper region of the earth, i.e. the crust which consists of the continental shelf and oceanic areas. The continental shelf is the part of the sea floor next to a land mass above which the maximum depth of water is 200m.

continental shield: the oldest rocks of a continent consisting mostly of igneous and metamorphic rocks which have subsequently remained unaffected by geological processes.

eucaryotes: organisms in which the cells have a true nucleus bounded by a nuclear membrance, and also possess membrane-bound cellular structures. cf. procaryotes

food chain: a hierarchy of food consumers, e.g. plants are consumed by herbivorous animals which in turn are fed upon by carnivorous predators.

galaxy: a system of stars, dust and gas existing in space. The earth exists in one galaxy; there are many other galaxies also.

grazer: a herbivorous animal feeding on grass or non-woody plants. cf. browser.

greenhouse effect: over-production of heat-absorbing gases such as carbon dioxide, methane and chlorofluorocarbons resulting in higher retention of heat in the atmosphere causing warm temperatures as in a greenhouse.

gymnosperm: a plant in which the seeds are naked, i.e. not enclosed within an ovary, e.g. conifers such as pines or cycads which bear seeds in cones.

inter-glacial: warm period between two glaciation events.

isotopes: two or more forms of an element differing from each other in atomic weight but not in chemical properties.

mammoth: a massive relative of the elephant which evolved during the Pleistocene glaciations. Some species like the woolly mammoth were highly adapted to the Ice Age conditions owing to their thick furry coats.

mastodon: a huge relative of the elephant which evolved before the Pleistocene glaciations but survived during them.

micaceous: consisting of mica which is a group of minerals containing silica and especially characteristic of seas and oceans.

ozone: form of oxygen with three atoms in the molecule.

phylum: a group of plants or animals which share certain unique features, e.g. Phylum Porifera consists of sponges. Phylum Annelida includes worms. (plural = phyla)

procaryotes: organisms such as bacteria and blue-green algae which have no true nucleus, no nuclear membrane and lack membrane-bound cellular structures such as mitochondria and chloroplasts. cf. eucaryotes.

savannah: grassland with scattered trees or shrubs.

solar system: a system of celestial bodies governed by a sun, e.g. earth's sun and the planets orbiting around it.

surface tension: force acting on surface of liquid which tends to minimise the surface area of the liquid.

warm-blooded: capable of maintaining constant body temperature, e.g. birds and mammals. cf. cold-blooded.